NESDI Project #451
Navy Demonstration of Cadmium and Cr^{+6} Compliant Electrical Connectors with Hermetic Seals

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ASETS Defense – San Diego, CA
27 August 2012

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012		**00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Navy Demonstration of Cadmium and Cr+6 Compliant Electrical Connectors with Hermetic Seals	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NAVAIR 4.3.4.6, Corrosion & Wear Branch,San Diego,CA,92135**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the ASETSDefense 2012: Workshop on Sustainable Surface Engineering for Aerospace and Defense August 27-30, 2012, San Diego, CA

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**30**	

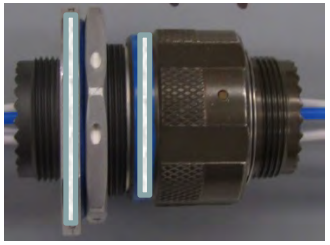
Outline

- Project Team – NAVAIR 4.3.4 (Materials Division) & 4.4.5.3 (Wiring Systems)
  - Ollie Muja and Brian Vetter, NAVAIR Wiring Branch
  - Joint Service Wiring Manual 01-1A-505-1; Joint Services Wiring Action Group
- Introduction
  - Alternative connector finishes overview
- Technical Objectives – MIL-DTL-38999 Environmental
  - Plating Evaluation
  - Wiring materials of construction and connector improvements
- Environmental Testing Results – 12 months harsh beachfront exposure conditions, no maintenance
  - Post-test corrosion images, exterior/interior of connector couples
  - Electrical tests
  - De-couple torque values
- Conclusions and Recommendations

Introduction

Finish Selection Overview

- AL6xxx vs. composite connector substrates:
  - Al connectors are more physical damage tolerant and provide better shielding than composite, thus still required for some applications. Composite has better corrosion resistance. Stainless steel- limited use in aerospace.
- Class W (Cd on Al), Class J (Cd on composite)
  - Control baselines, Class W (2.5 mΩ), Class J (3.0 mΩ). Cd is prohibited in some aircraft zones.
- Nickel (Class F), Nickel-PTFE (Class T)
  - Industry favors Ni for superior electrical performance over cadmium (Class F=1 mΩ ; Class T=2.5 mΩ). Will likely require special measures such as connector gaskets for long term protection on structure such as Al, but better for other substrates -Ti, composite.
- Class Z (Zinc-nickel), 2.5 mΩ
  - One qualified source at beginning of this testing; two sources tested.
- Class P (high-purity Al) – Good corrosion protection but no qualified sources
- Tin-Zinc – Alternate, not tested on -38999 shells



Test Objectives

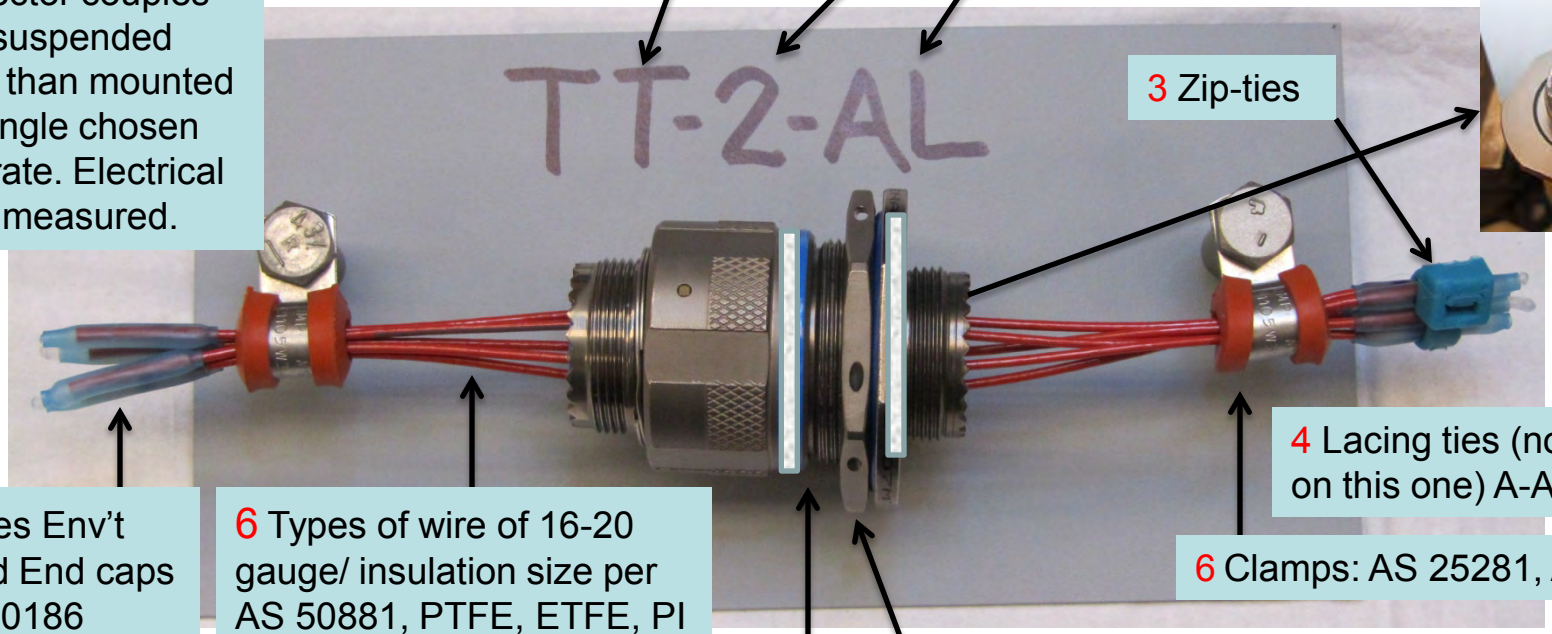
1. Connector Finish environmental durability
2. Evaluate wiring materials-of-construction

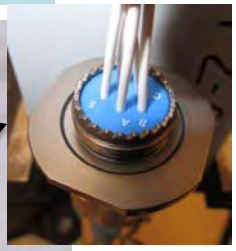
3 or 4 replicates of most couplings

10 Plating Config's

Al and Composite Substrates

Connector couples were suspended rather than mounted to a single chosen substrate. Electrical drops measured.





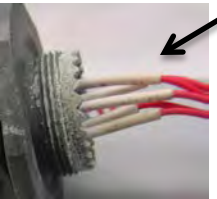
3 Zip-ties

2 Types Env't sealed End caps D436-0186

6 Types of wire of 16-20 gauge/ insulation size per AS 50881, PTFE, ETFE, PI

4 Lacing ties (not shown on this one) A-A-52083

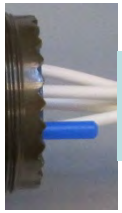
6 Clamps: AS 25281, AS21919



23053/5 heat shrink used to increase CMA to test sealing

Couple/De-couple durability (50+ cycles prior to test, and periodically in environment)

MIL-DTL-38999 Series III Jam nut style, EMI, environmental rated connectors, pin count 5, receptacles and plugs pinned, Cu-Be EMI fingers



Sealing Plugs

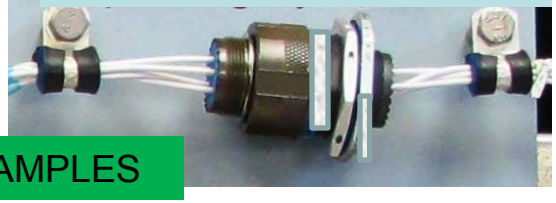
Plating Evaluation Goals

- In Navy / Marine Corps operational environment in worst-case no CPC maintenance situation:
  - How do the new finishes compare to Cad and Class F (EN) controls?
    - Couple/de-couple connector pair 50X before environmental testing
    - Periodic opening
  - Evaluate back compatibility with controls?
  - Is multi-layer plated Class T (Ni-PTFE) better than EN on Al?
  - Any concerns when composite substrates are included in the design?
  - How does manufacturer's Dry film lubricant (DFL) perform (Class P)?

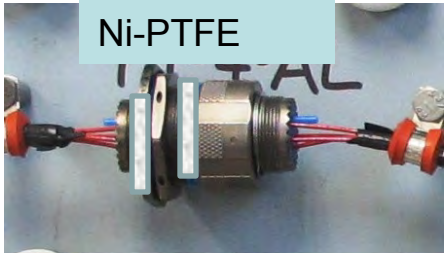
EXAMPLES

Cad on composite controls

Cad to high-purity Al (HPA)



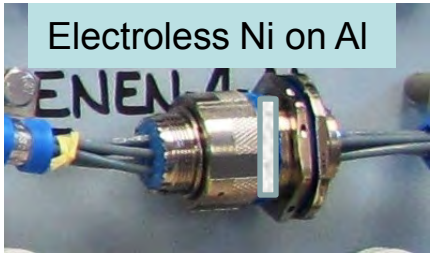
Ni-PTFE



Cad on Al to Cad on composite

Cad on Al controls

Electroless Ni on Al



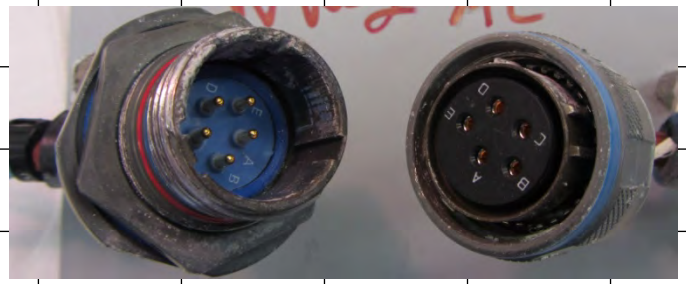
Plating Evaluation Goals

- Seventy (70) fully pinned connector couplings evaluated: Electrical performance, de-coupling torques, galvanic corrosion

Cd Controls

Class Z x 2

	Class W (Cd on Al)	Class J (Cd on Comp)	Class P (HPA on Al)	Class T (Ni-PTFE on Al)	Class F (EN on Al)	Class T (Ni-PTFE on Comp)	Class Z #1	Class Z#2	Class M (Ni on Comp)	Sn-Zn
Class W (Cd on Al)	X 4									
Class J (Cd on Comp)	X 4	X 4								
Class P (HPA on Al)	X 4	X 3	○							
Class T (Ni-PTFE on Al)	X 4			X 4						
Class F (EN on Al)	X 3			X 3	X 4					
Class T (Ni-PTFE on Comp)						X 4				
Class Z #1	X 3		X 3				X 4 ●			
Class Z#2		X 1			X 1			X 2		
Class M (Ni on Comp)	X 2				X 4			X 1	X 4	
Sn-Zn										X 4 ●

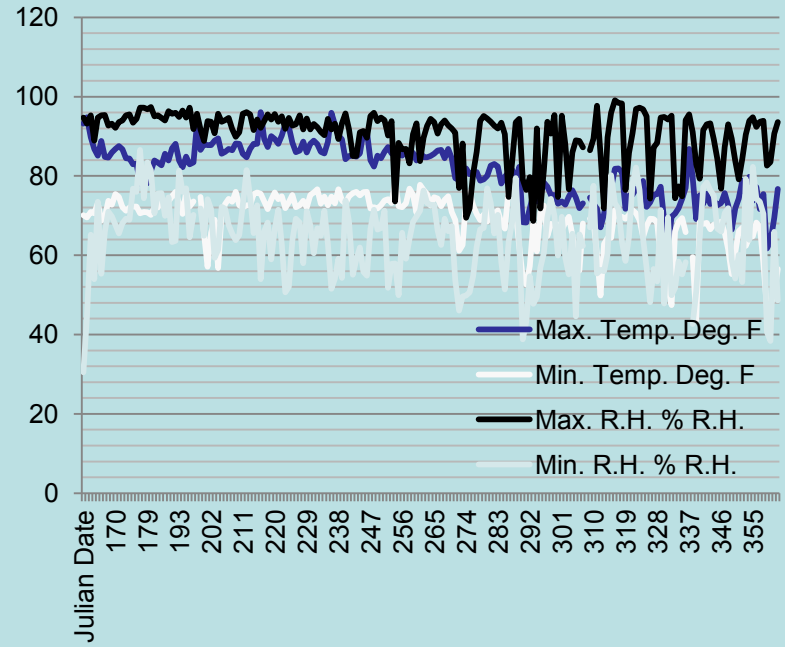


● = Did not pass as-received coupling torque req't

Environmental Test Site

- NASA Kennedy Space Center (KSC) was employed as the site for suitability testing of the assemblies due to its very high corrosion rate. NAVAIR has test racks situated there which have been testing various coatings for 10 yrs (ESTCP NCAP, etc.).

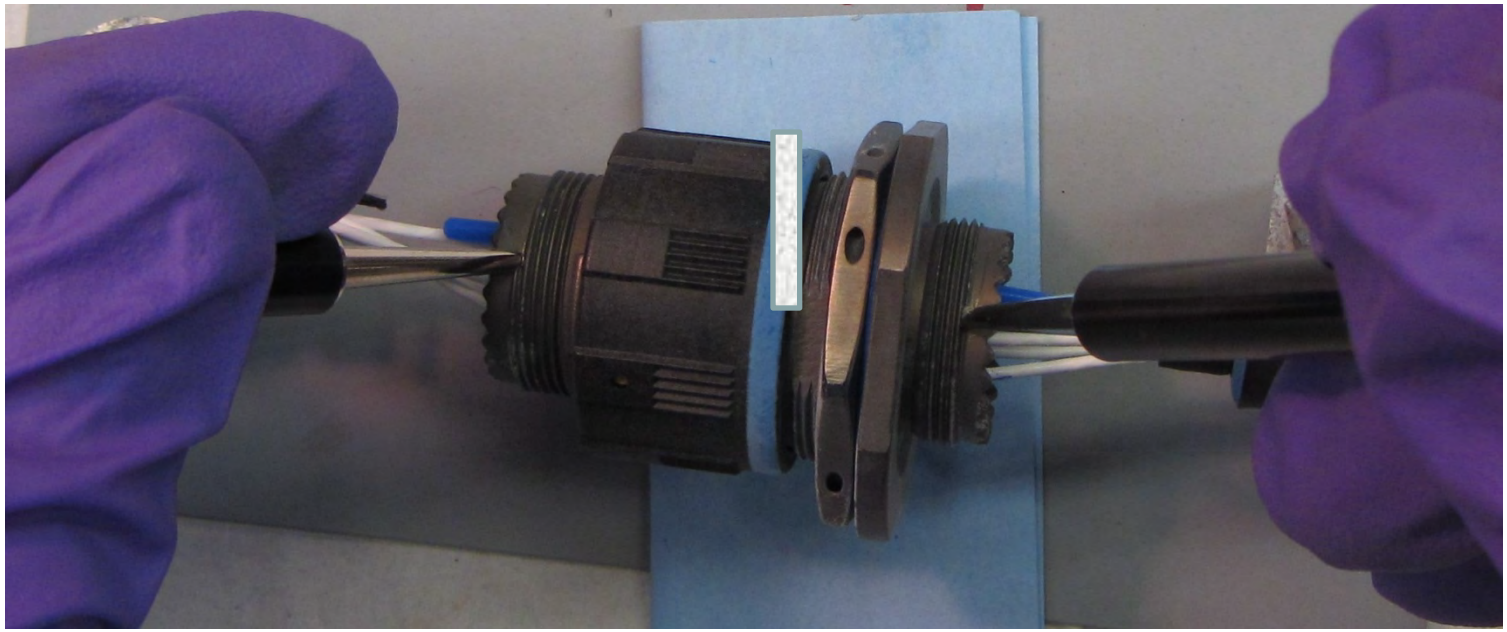
Actual weather data, 1st six months of testing at KSC



Testing started 16 June 2011

Electrical Test

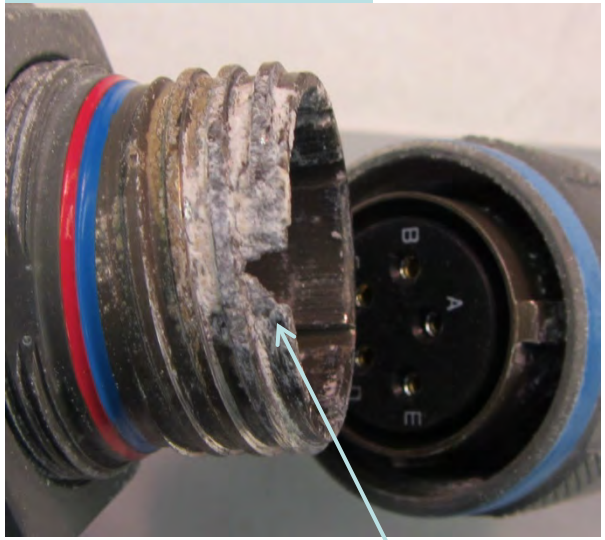
- Procedure used was adapted from Sec. 4.5.25 MIL-DTL-38999 as we did not have backshell shielding installed
  - At current 1A, 2.5 m-ohm (1 m-ohm EN); after corrosion test (ASTM B 117, 500h) higher resistances allowed, nominally double
  - We plotted values in relation to controls for comparative purposes as the environmental test was non-standard



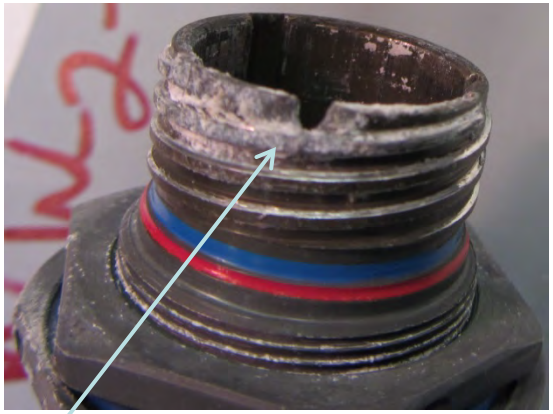
Class W Cd/Cr^{+6} Control – 12 mos.

- Significant salt & corrosion product especially on one couple, difficult to open:
  - Class W cadmium/Cr^{+6} had corrosion ‘chip’ at receptacle keyways

Class W Cadmium



Spread of resistance values observed: 1, 3, 25, 65 m-ohm (23 m-ohm avg.)



Corrosion ‘chips’ at keyways on three (3) of four Cad on Al connectors (WW-x-AL). Test method reproduced observations in Fleet

Class W Cadmium

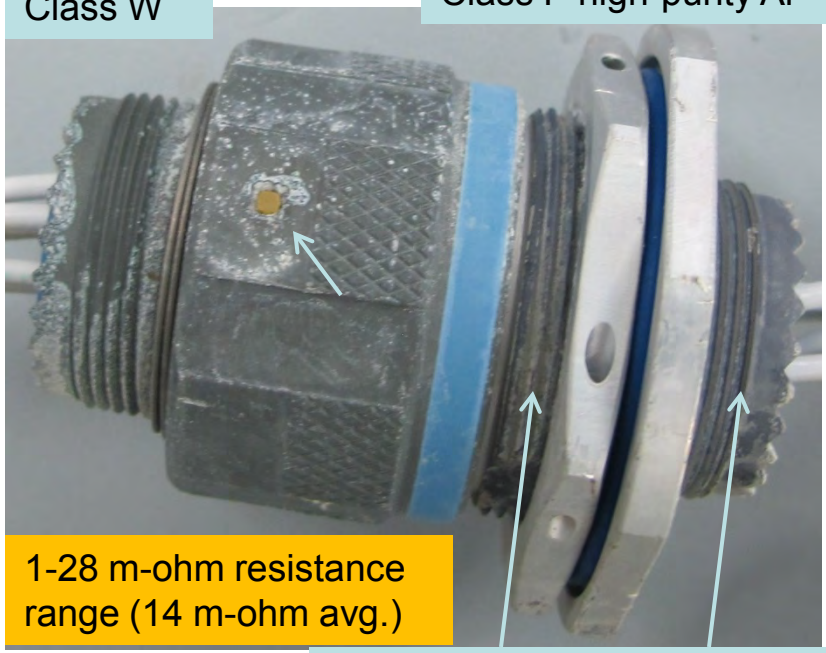
Vise required to open quite a few of the Al connectors, incl. cadmium plated

Cad / HPA on Al – 12 mos.

- Top Performers on Al connectors at 12 months KSC testing:
  - Class W Cad/Cr^{+6} looks good externally except for sacrificial corrosion, more pronounced adjacent to dissimilar metals (copper alloy) and some threads
  - Class P high-purity Al had lowest average resistance of any aluminum connector couple (WP-x-AL)

Class W

Class P high-purity Al

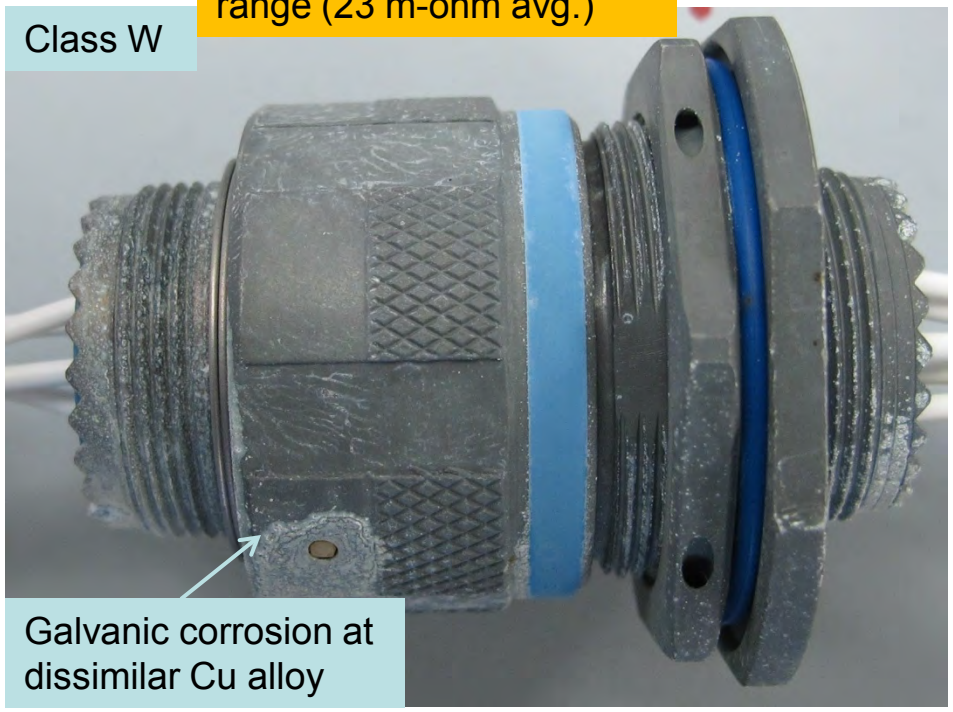


1-28 m-ohm resistance range (14 m-ohm avg.)

Dry film lube on HPA coating OD threads

Resistance 1-65 m-ohm range (23 m-ohm avg.)

Class W

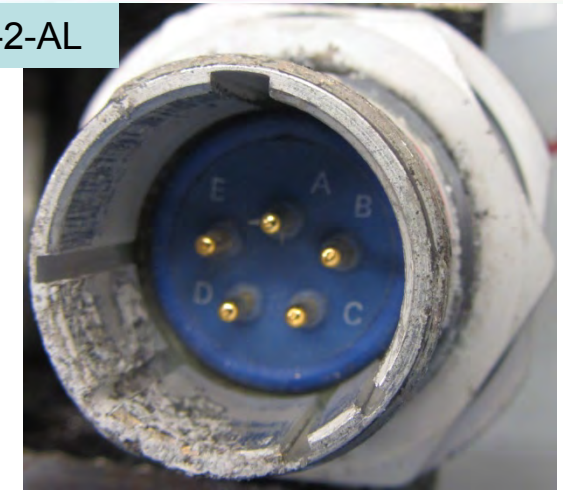


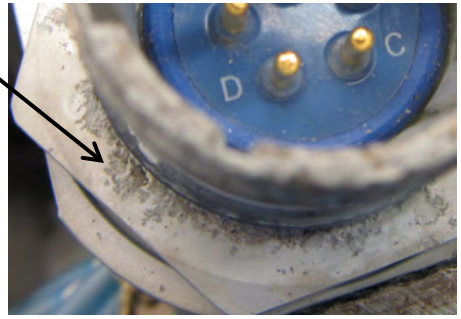
Galvanic corrosion at dissimilar Cu alloy

HPA – 12 mos.

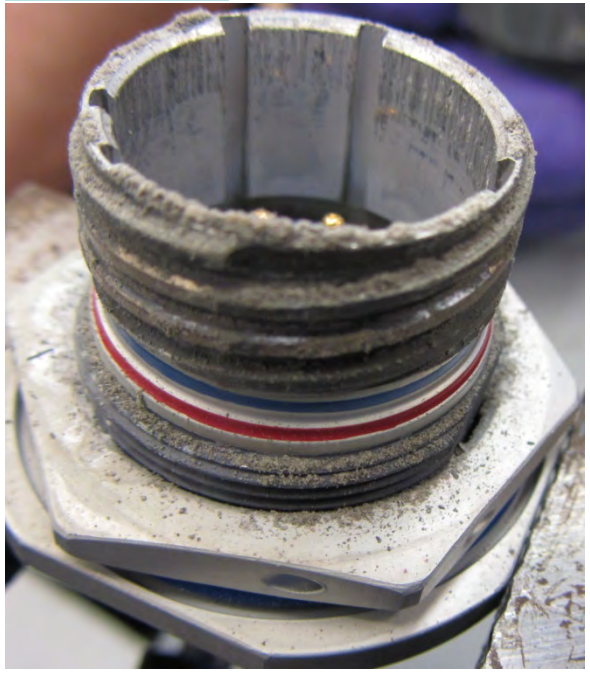
- HPA Interior conditions (Coupled with Cad on Al)
  - Class P has some scoring on receptacle I.D.
  - Corrosion on jam nut face
  - No ‘chip’ corrosion

WP-2-AL

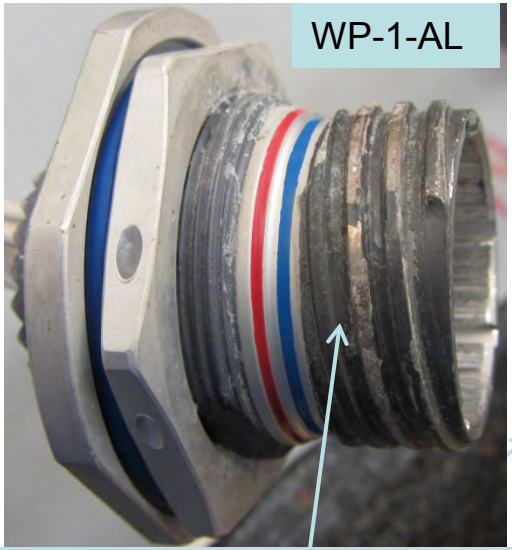




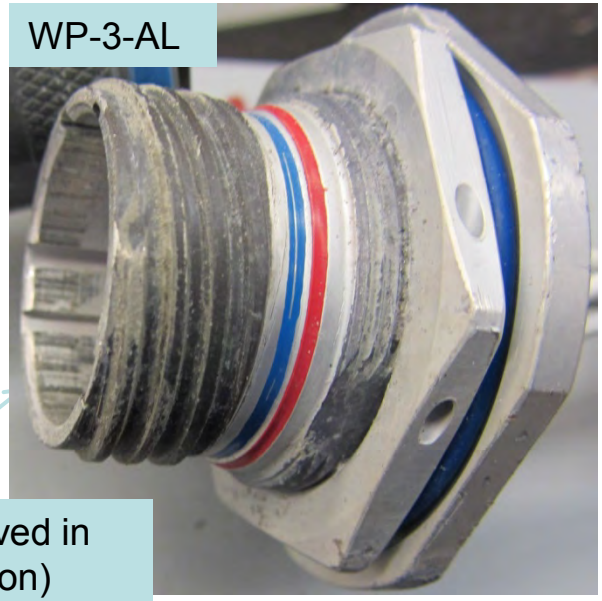
WP-1-AL



WP-1-AL



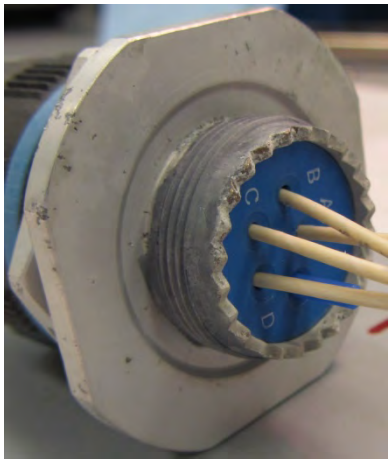
WP-3-AL



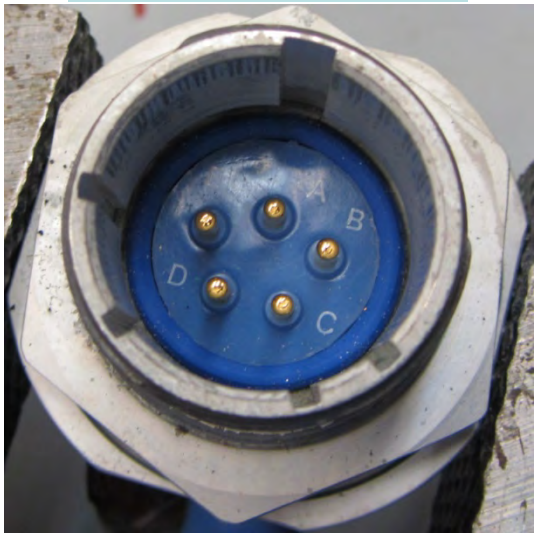
DFL is good condition some places, removed in others (may see underplate but no corrosion)

HPA / Composite – 12 mos.

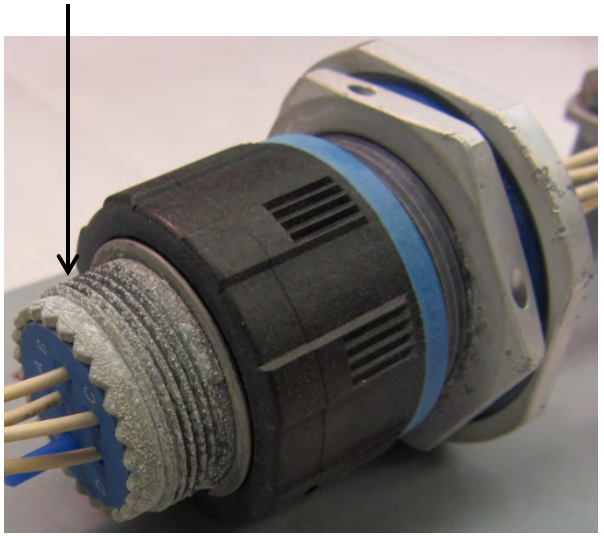
- Interior conditions:
  - Class P has some scoring on receptacle I.D. (EMI finger ring witness marks)
  - Slight corrosion spots on jam nuts



JP-2-AL, coupled to composite plug



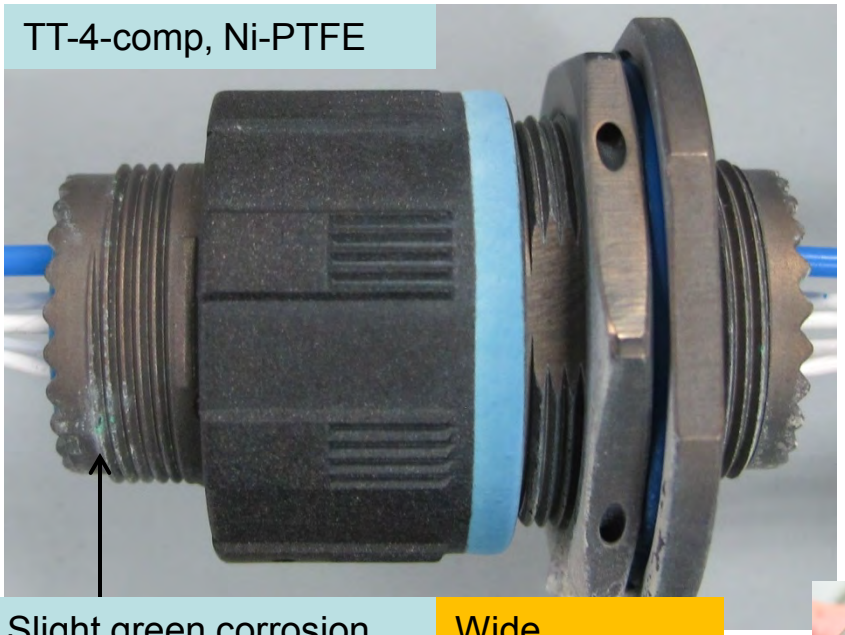
JP-3-AL, coupled to composite plug w/Cad at backshell – lot of sacrificial Cad corrosion



Class T on composite

- Class T finish (Ni-PTFE) on Composite - 12 months KSC testing:
  - Finish performed well on the composite substrate except at 1-2 spots on the jam nut (Al construction)

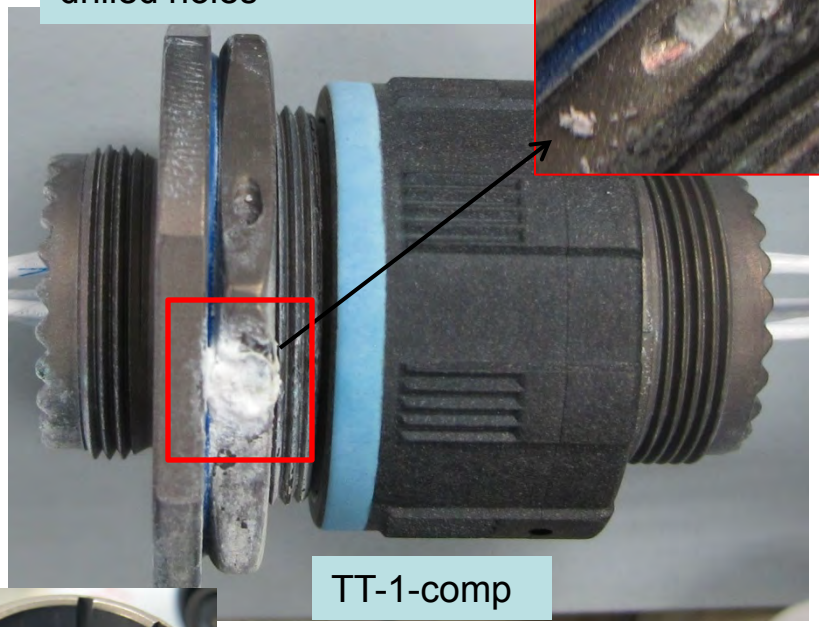
TT-4-comp, Ni-PTFE



Slight green corrosion product at finer threads

Wide resistance spread:15, 18, 70, 600 m-ohm

Al Jam nuts have 1-2 corrosion sites on one of 3 drilled holes



TT-1-comp

Interior conditions are excellent

Composite - 12 mos.

- 12 months KSC testing, Class J (cadmium on composite) and Class M (nickel on composite) – both relatively easy to open and maintained low resistance values

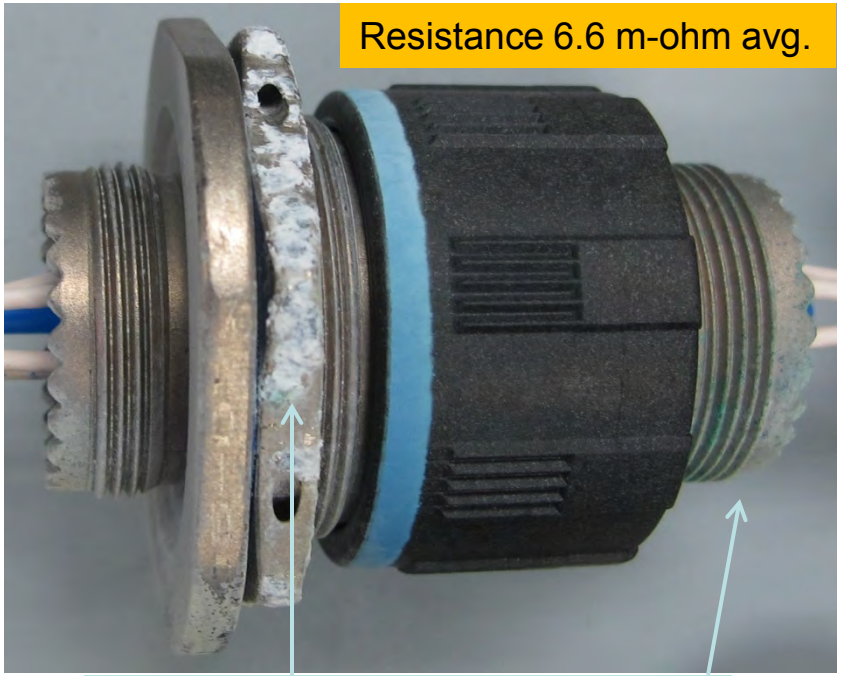
JJ-2-comp, Class J cadmium on composite

Resistance 5.8 m-ohm average

Cadmium corrosion product is evident especially on threads

MM-1-comp, Class M, Nickel on composite

Resistance 6.6 m-ohm avg.

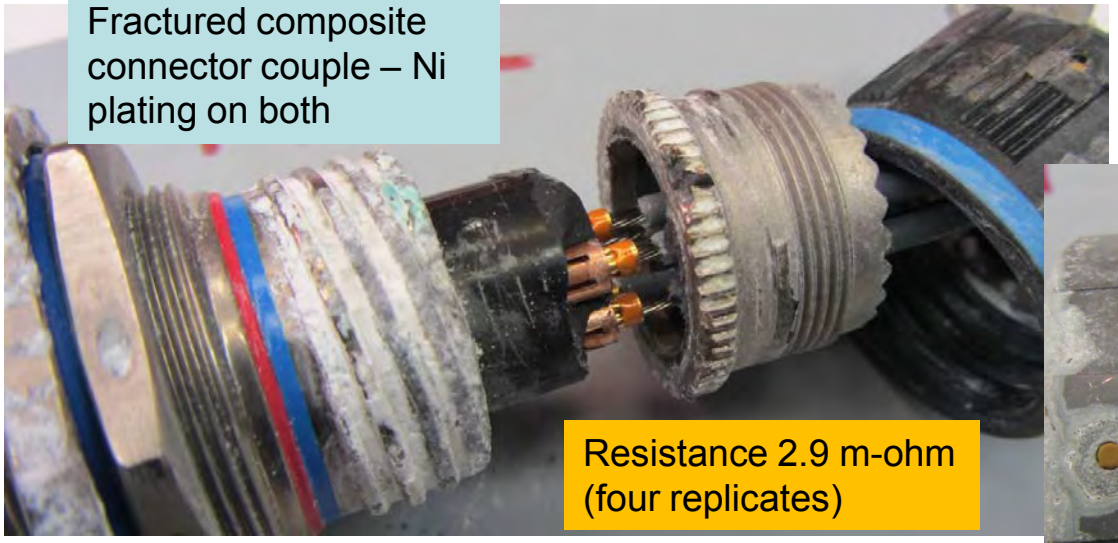


Green corrosion product on smaller threads (copper strike?) and white corrosion on the jam nut

Composite - 12 mos.

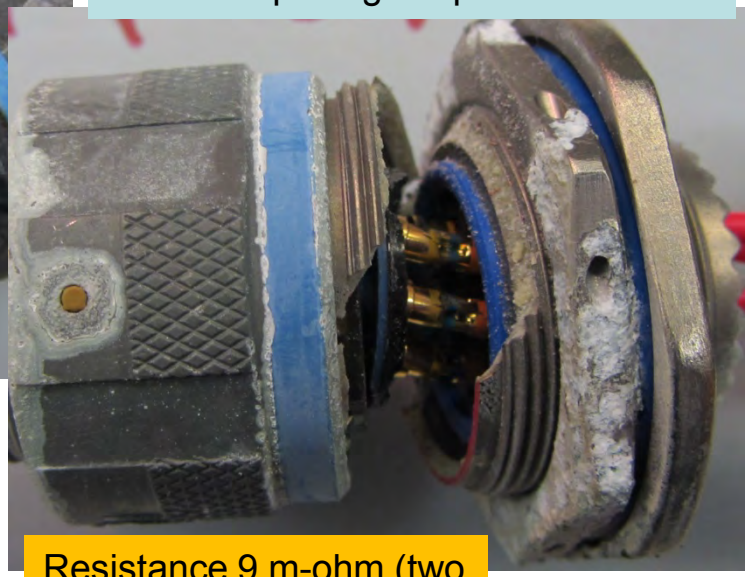
- Detriments to using composite:
  - Class M (EN on composite) to Class F (EN on Al) couple, seized (Left). Broke 3 of 4 couples during opening; resistance exceptional at 2.9 m-ohm(!).
    - When should you maintain a corroded connection if electrically sound?
  - Class M (EN on composite) to Class W Cad plug, broken (right)

Fractured composite connector couple – Ni plating on both



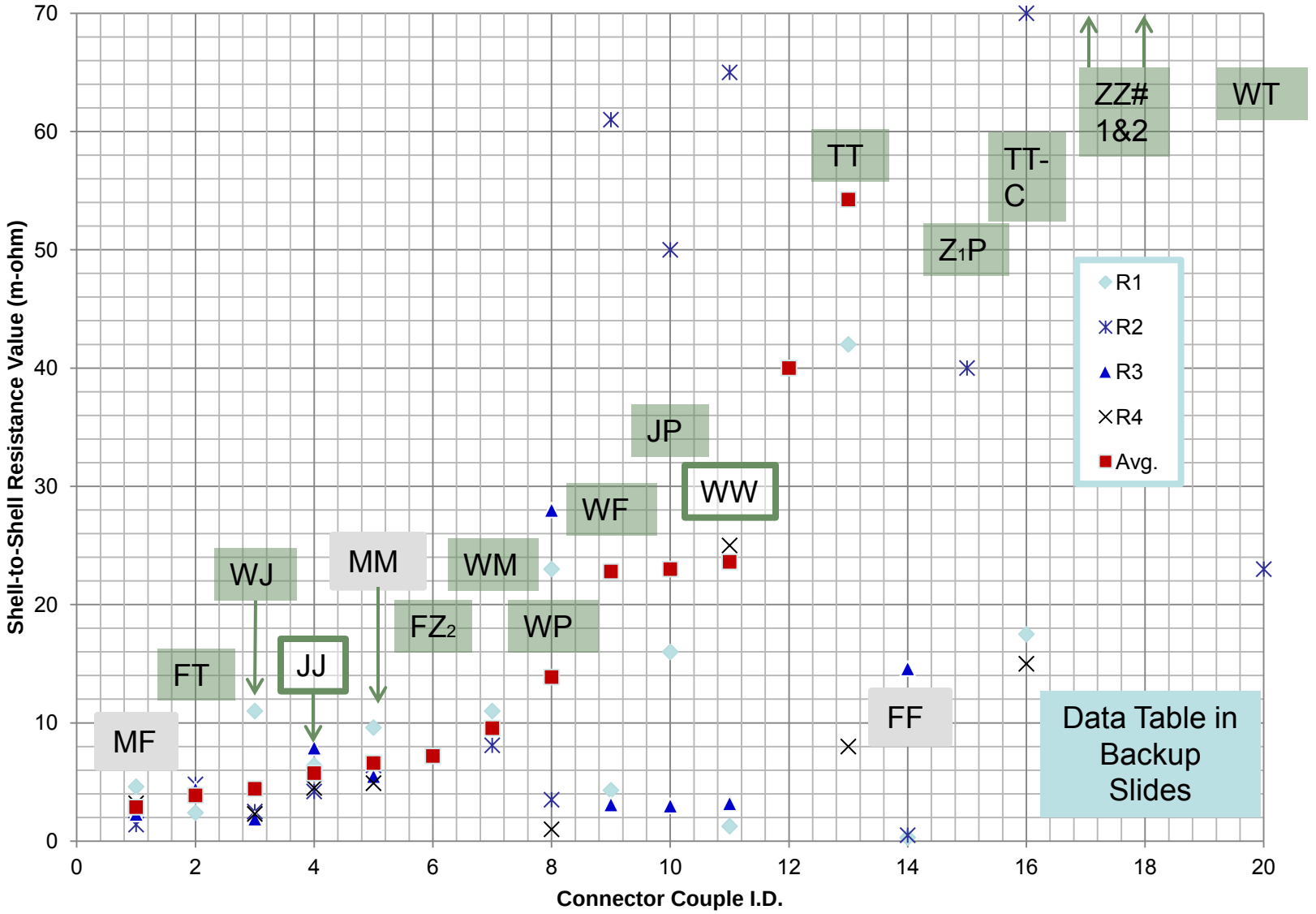
Resistance 2.9 m-ohm (four replicates)

Broken Class M, Ni-on-composite receptacle in Class W plug – dissimilar plating couple



Resistance 9 m-ohm (two replicates)

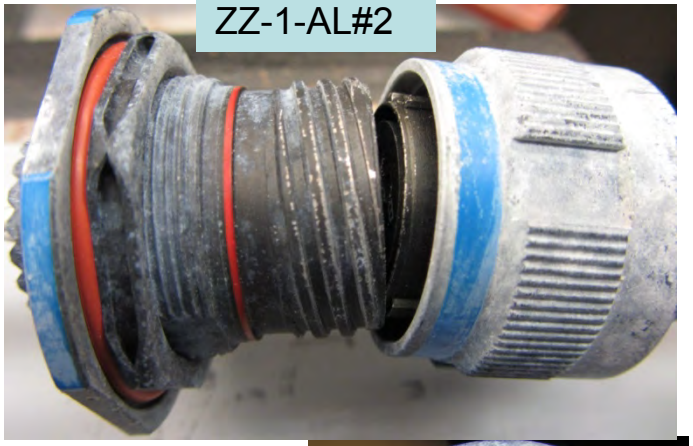
Electrical Performance Summary – 12 mos. KSC



Class Z #2 – 10 mos.

- One Class Z (Zn-Ni) product developed a sacrificial corrosion layer
  - Reportedly, the company uses a hex-Cr post-treatment which meets the European RoHS guidelines threshold for 0.1 wt.% of the part
  - No corrosion 'chip' as seen on Cad plating

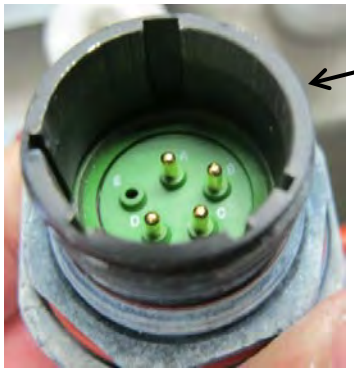
ZZ-1-AL#2



Plating flaking seen on several receptacle backsides

Elevated 150-300 m-ohm resistivity values

Plug ZZ-1-AL#2



Internals, keyways are in good shape

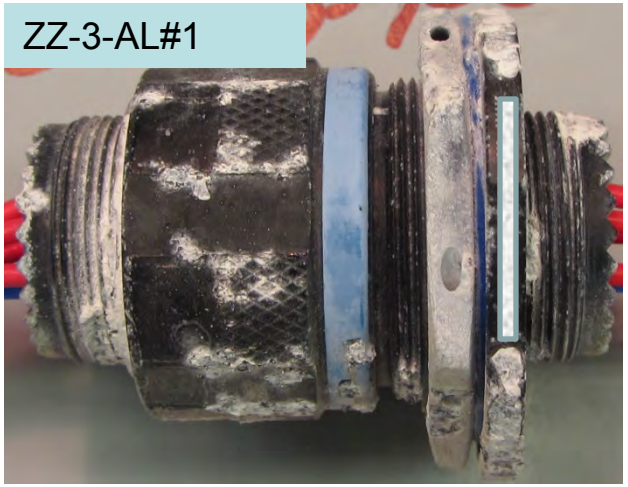
Class Z #1 – 12 mos.

- Class Z #1 had corrosion and seizing issues similar to worse than Class F (EN/Al)
  - Loss of plating at flanges due to connector wrenches at KSC
  - Resistance values were consistently high at small thread measurement points

ZZ-2-AL#1

Class Z #1 couples were seized and have not yet been opened

ZZ-3-AL#1



ZZ-(1-4)-series 180-400 m-ohm resistance range

Decoupling Torques post KSC* (in-lb)

Measured at NAVAIR Wiring Lab with connector strap wrench.

*Note: Some couples had been connector-wrenched open at KSC a couple weeks prior while others were seized. This will skew some points downward, but the high values are known.

Connector Finish	T1	T2	T3	T4	Avg. T in-lb
MF-x-AL	50+	75+	75+	75+	75+
FT-x-AL	75+	75+	75+		75+
WJ-x-comp	50	75+	15 ★	10 ★	38+
JJ-x-Comp	5	15	20	20	**15**
MM-x-comp	5	5	10	10	**8**
FZ-2-AL-#2	75+				75+
WM-x-comp	25	75+			
WP-x-AL	5 ★	10	115	100+	43
WF-x-AL	75+	75+	75+		75+
JP-x-AL	2.5 ★	2.5 ★	2.5 ★		**3**
WW-x-AL	7.5 ★	7.5 ★	45	75+	20
ZJ-1-comp-#2	10 ★				**10**
TT-x-AL	100+	100+	70	100+	100+
ENEN-x-AL	100+	100+	100+	125+	100+
ZP-x-AL	125+	125+	125+		125+
TT-x-Comp	5 ★	2.5 ★	5 ★	15 ★	**7**
ZZ-x-AL-#2	7.5 ★	10 ★			**9**
ZZ-x-AL	125+	100+	100+	100+	100+
MZ-3-AL-#2	35				**35**
WT-x-AL	25	50	25	100+	33
WZ-x-AL	15	75+	75+		55+
SnZn-x-AL	10	10	15	10	**11**

Improved electrical performance (from previous slide)

★ Most recently opened onsite at KSC

NOTE: 75+, 100+ and 125+ values were due to concerns with strap wrench strength concerns.

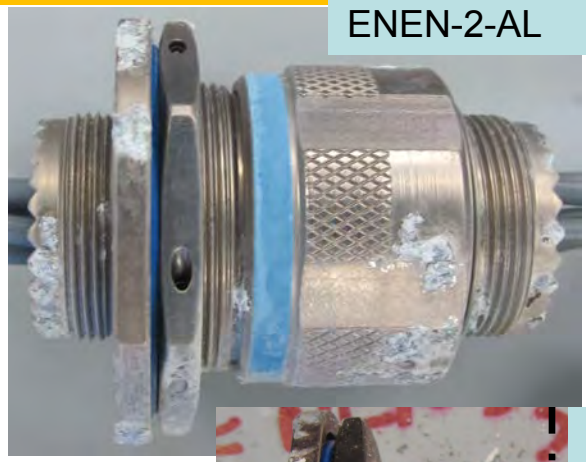
Class F – 12 mos.

- Electroless Nickel; Corrosion pitting especially where connector wrenches were used
  - Resistance values exceptional for two couples; one moderate, one high
  - Could not open, seized

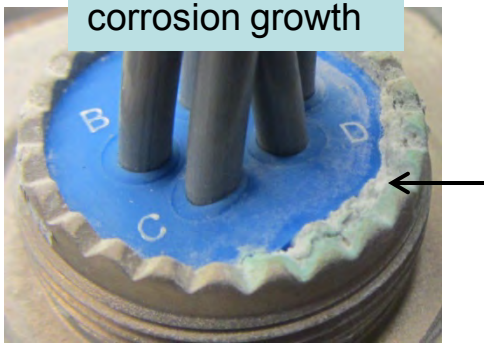
ENEN-1-AL

Two resistance values still pass spec @ 0.3, 0.5 m-ohm [+ 14.6, one high]

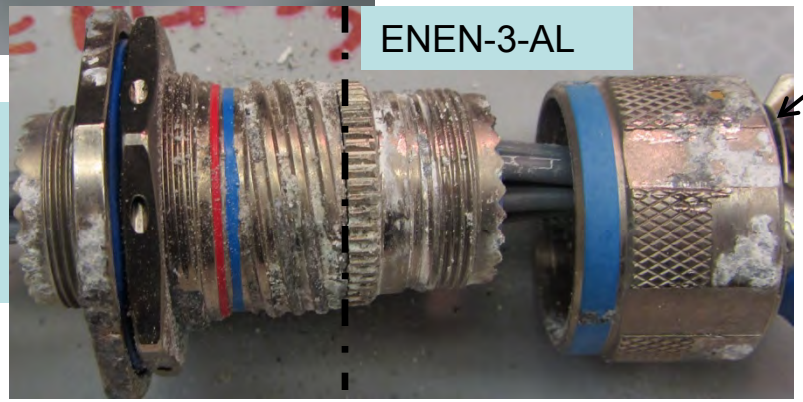
ENEN-2-AL



Buckled sealing grommet due to corrosion growth



ENEN-3-AL

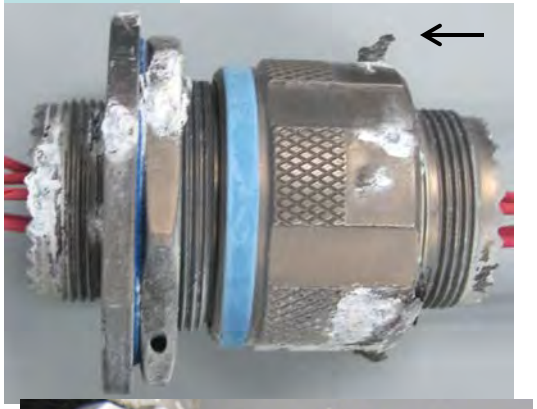


After CPC spray into thread crevice, connector plug retainer failed when forcing open

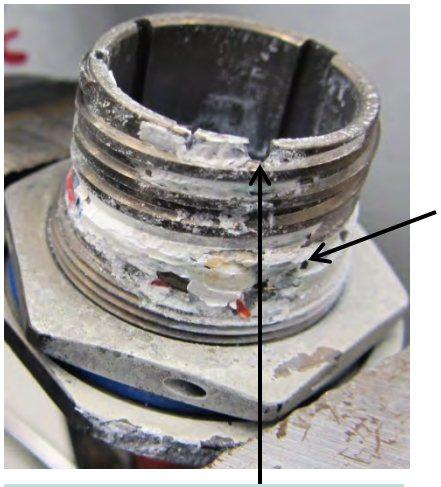
Class T on Al – 12 mos.

- Multilayer Ni-PTFE was expected to improve corrosion resistance by limiting time-of-wetness; this vendor's candidate did not perform better than Class F (EN on Al) but were able to be opened
  - As with Class T on composite, resistance values were elevated above EN on the same substrate

TT-3-AL



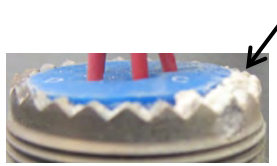
TT-2-AL



Corrosion 'chip' at low side of receptacle (not master keyway)

Resistance range 8-94 m-ohm (54 m-ohm avg.)

Plug internals-clean



Buckled sealing grommet of connector caused by corrosion growth on inner surface

Class T to Cad – 12 mos.

- Class T Ni-PTFE to Cad:
  - Largest ‘wave’ of sacrificial Cad corrosion on plug shown below

WT-4-AL, Class T on Al to Cad

Higher Cad corrosion rate – discoloration on plug

WT-2-AL, 23 m-ohm

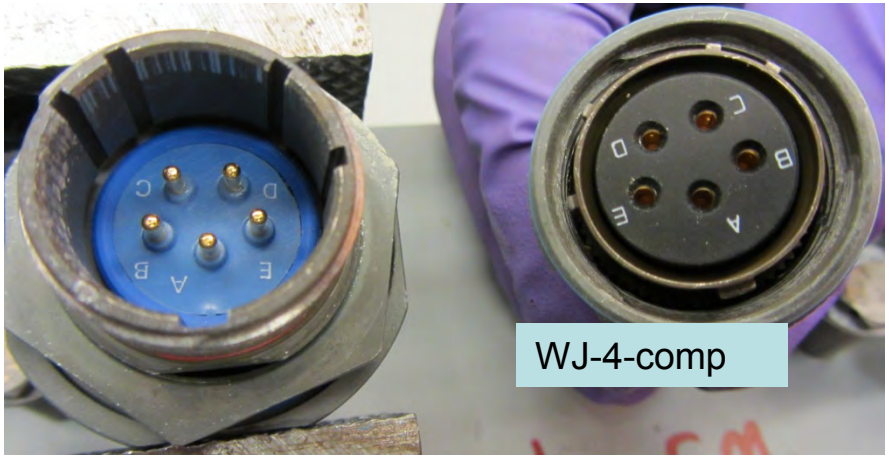
Resistance range 23-3100 m-ohm

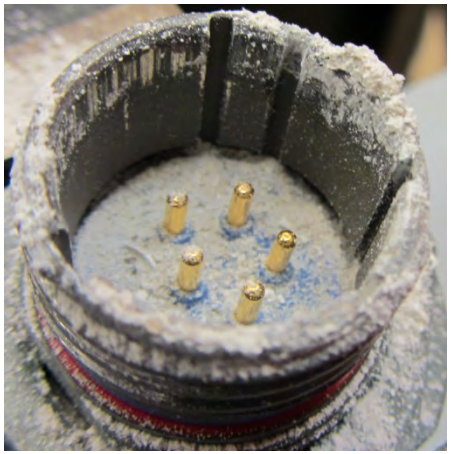
WT-1-AL, >3000 m-ohm

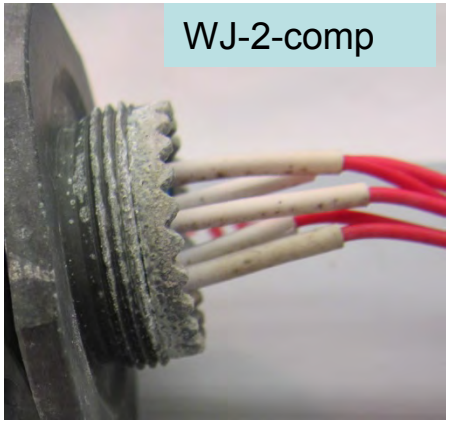
Composite - 12 mos.

- Class J Cad-on-composite to Class W (Cad on Al):
  - One of four connectors seized up, sealing effect of backshell may have been lessened by wire/insulation size gap

Resistance 1.9-11 m-ohm
(4.4 m-ohm avg.)







23053/5 heat shrink used to increase CMA & test sealing

Tin-Zinc Electroplate – 12 mos.

- This coating is the least mature with respect to test/qualification (soft plating & lubricity may be issues without appropriate thread lube)
  - Electrical values not directly comparable to other candidates as the same pinned -38999 configuration was not available

Tin-Zinc plating was applied to blank aluminum shell components

Resistance range 100-300 m-ohm – not pinned -38999 connectors like other plating systems

Observations & Recommendations

- MIL-DTL-38999 Connector Performance:
  - Because of the reasonable exterior appearance of many connectors, thread lube/CPC was not introduced during this year long test –
  - Most marking inks were not UV stable enough to survive this test
  - The red and blue marking lines stayed on well, good UV compatibility
  - The blue and green fluorinated gaskets remained in excellent condition
  - Composite connectors had better / lower de-coupling torques, although some of the composite connectors fractured when trying to remove seized couple – dissimilar mates of Al/composite connector bodies will likely cause maintenance issues
  - Recommend: Protect EMI finger ring corrosion with suitable plating or (conductive) dry-film-lubricant at OEM level [plugs not yet dissected for complete documentation]
  - Recommend: Redesign seal/gasket to receptacle side to control keyway/thread corrosion which was largely responsible for corrosion/seizing

Plating Performance Summary

- Plating Finish :
  - Class W Cad – Corrosion ‘chip’ at master keyway on receptacles; not consistently low resistance; some high removal torques
  - Class P (HPA) – Overall very good performance and compatible with W and J Cad connectors; DFL adhered and protected well, and where removed there was no corrosion
    - Lack of submittal of Class P matched plug/receptacle couple prevented it’s inclusion in these results
  - Nickel coatings – May benefit from special conductive connector gaskets for installation on certain substrates (in lieu of paint/sealant)
    - Class F – Maintained low resistance (3 of 4 couples) but seized due to corrosion
    - Class T (Ni-PTFE) – Plating corrosion failures more substantial than Class F, degraded electrical properties; no substantial improvement in seizing tendency
    - Class M – Ni-on-composite electrical performance benefits
  - Class Z – Zn-Ni
    - #1, Poor overall corrosion and electrical performance, seized
    - #2, Repeatable localized plating adhesion loss on receptacle, poor electrical performance
  - Sn-Zn wasn’t compared directly on 38999 parts protected the Al connector

Conclusions and Recommendations

- For aluminum electrical connector shells:
  - HPA is the most viable Cd-alternate candidate from those tested
  - Class T offered no advantage over Class F (EN); development targets should focus on electrical resistance degradation, corrosion response, and significantly improve seizing tendency
  - Class Z finishes underperformed
    - Not suitable for the harshest environments; if specified in more benign environments, life-cycle performance should be evaluated. [Higher Ni formulations may extend the envelope]
  - Tin-zinc is worth another look on production-representative -38999
- On composite shells:
  - EN on composite had good electrical performance
    - Electrical connector gaskets may need further evaluation for life-cycle effects on aluminum substrates
- Al connectors should have a suitable CPC maintenance plan at least for threads – brush applied on receptacle threads to limit overspray (guidance documents need updating)

Backup Material

Data for slide 16 ("Electrical Performance Summary 12-mo KSC resistance values)

Connector Finish	R1	R2	R3	R4	Avg.
MF-x-AL	4.6	1.4	2.3	3.2	2.875
FT-x-AL	2.4	4.8	4.4		3.866667
WJ-x-comp	11	2.5	1.9	2.3	4.425
JJ-x-Comp	6.4	4.2	7.9	4.5	5.75
MM-x-comp	9.6	6.4	5.5	4.9	6.6
FZ-2-AL-#2	7.2				7.2
WM-x-comp	11	8.1			9.55
WP-x-AL	23	3.5	28	1	13.875
WF-x-AL	4.3	61	3.1		22.8
JP-x-AL	16	50	3		23
WW-x-AL	1.26	65	3.2	25	23.615
ZJ-1-comp-#2	40				40
TT-x-AL	42	73	94	8	54.25
ENEN-x-AL	0.3	0.5	14.6	320	83.85
ZP-x-AL	150	40	243		144.3333
TT-x-Comp	17.5	70	600	15	175.625
ZZ-x-AL-#2	300	157			228.5
ZZ-x-AL	300	180	400		293.3333
MZ-3-AL-#2	600				600
WT-x-AL	3100	23	93	870	1021.5
WZ-x-AL	11000	180	140		3773.333